Final Technical Report for NASA Grant NAG5-1116

Support period: January 1, 1989 - December 31, 1990

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During the past two years, the Cornell University Portable Radar Interferometer (CUPRI) has been used to provide the key launch criterion for the ERRRIS I and II auroral electrojet rockets. The second of these two years was partially funded by NASA Grant NAG5-1116 and included support for the data acquisition phase of the ERRRIS II campaigns and for data analysis of both. Three NASA sounding rockets were flown from ESRANGE, Sweden during concurrent observations with CUPRI. Results from a preliminary analysis were forwarded to our Technical monitor, Dr. R.F. Pfaff, by J. Sahr as an interim progress report. This report summarizes progress for the year of funding, but there still remains much to be done. Many of the coordination details for comparing data from all the different instruments involved in the ERRRIS campaign were discussed at the workshop of February 6-7, 1990. Some of the CUPRI ERRRIS data is providing the basis of a Ph.D. thesis [Sahr, 1990], and has led to a paper that is now accepted for publication in Radio Science [Sahr et al., 1990].

Portions of the CUPRI data set corresponding to rockets 21.100 launched at 18:17:14 UT on 1989 March 3 and 21.096 launched at 01:02:47 UT on 1989 March 4 are included in this report. Tables 1 and 2 list the CUPRI operating modes for these two launches. Either single or double pulses were transmitted with interpulse periods (IPP's) between 2 ms and 6 ms (listed in microseconds in the tables). A pulse separation of 240 μs was used for the double pulse cases. (A zero tau indicates a single pulse mode.) The figures corresponding to each launch are grouped together with the two mode summary tables.

The processing and presentation of CUPRI data depends on the operating mode used and falls into one or more of four general categories. The first is the simple RTI (for Range Time-Intensity) analysis that is generally presented in the form of a gray scale. Such plots are useful in showing when and where there are regions of irregularities that scatter the radar signals and were used to monitor conditions as part of the launch criterion. Examples of RTI type plots that were created off-line are shown in Figures 1, 2, 10 and 11. Figures 2 and 11 expand the time and range scales for the periods about the launches. The examples cover a wide range of different conditions including times when instabilities covered most of the observable range, and other times when

echo characteristics were rapidly changing. RTI plots have been generated for the entire evening and late night hours of March 3-4 and are available upon request. Since short IPP's were used during the actual rocket flights, some care must be exercised in the interpretation of just where the echoes were coming from. It is altogether possible that some echoes that appear to be over ESRANGE may in fact be aliased in from longer ranges. Earlier data from this night of March 3-4 showed strong echoes coming from all ranges between 300 km and almost 900 km. Fortunately the range aliasing was not this extreme during the rocket flights, and we hope that a detailed analysis of the vertical interferometer data taken at this time (see below) will help sort out this problem.

The second category is the detailed spectral analysis. Complete spectra at all ranges are produced for every few seconds of real time. Examples of just a small portion of the spectra available are shown in Figures 3-9 and 12-17. We generally group auroral spectra into four types. The ERRRIS rocket payloads were designed to examine regions producing Type III and Type IV echoes. Originally we had thought that the Type III echoes were produced by ion cyclotron waves [Fejer et al., 1984]. Theoretical modelling showed that if this were to be the case, the waves would have to be generated well above the collisional electrojet region. However, recent vertical interferometer measurements with CUPRI indicate that the Type III echoes are produced within the electrojet region, and hence, the ion cyclotron wave theory seems to be no longer tenable, and the source of these waves remains an open question. Type III spectral candidates that were observed over ESRANGE prior to the launch of 21.096 seem to have been range aliased. The interferometer analysis should shed more light on this problem.

The theory of the Type IV waves seems to be on more solid ground. We have proposed that they are highly Doppler shifted two-stream waves caused by sporadic enhancements of the plasma temperatures [Fejer et al., 1986; Providakes et al., 1988]. EISCAT data acquisition programs were configured for high temporal resolution for the temperature measurements, and indeed we observed very short duration temperature enhancements [Providakes et al., 1988; Haggstrom, ERRRIS workshop discussions, 1990]. During the flight of 21.100 Type IV waves at about 600 m/s (aliased) were observed in the vicinity of the rocket (see Figures 4-7), but detailed locations for exact coincidence checks have not yet been worked out. Many of the spectra at ranges between 340 km and 400 km in Figures 5-7 show two distinct features, with one peak at about 250 to 300 m/s (Type I) and another at velocities varying from 400 to 600 m/s some of which are frequency aliased in from 1200 m/s (Type IV). It is unlikely that these have both come from the same spatial region, and the interferometer should tell us whether one of them was aliased in from longer ranges, or whether there was some east-west separation.

An example showing how frequency aliasing can be unraveled (the third analysis type) with the double pulse mode is shown in Figure 12. Here first moments are generated for each velocity (frequency) bin. Except for velocities between 300 and 550 m/s, both the spectrum and first moment estimates are very noisy. At Dopplers where the signal is strong, we find that the true shift is about -1200 m/s rather than +400 m/s. This technique for removing frequency aliasing is described in Sahr et al., [1989]. Many examples of Type IV spectra appear in Figures 13-16, where they have not yet been de-aliased to the correct Doppler shifts with the full double pulse analysis.

The fourth type of analysis we apply to CUPRI data is cross-spectral analysis between two or more receivers to recover echo positional information. The volume of the raw data required for this analysis and the volume produced is enormous. Two interferometer antenna baselines were used for the ERRRIS campaigns. One baseline is used to determine the azimuthal position of echoes within the 5 degree beam. The second gives the elevation angle which can be mapped into either a vertical or north-south position of the echo. This analysis is very compute intensive and we will do it only for data coincident with the rocket flights or other complementary measurements. Several key portions of our data set were identified for this complete analysis during the recent ERRRIS workshop at Goddard SFC.

This Grant was primarily intended to cover substantial costs of the campaign that were beyond that which could be provided by other sources. Since the funds of the Grant have been entirely expended, we will consider this as the final technical report. Much remains to be done, however, and we do expect to continue working with the various scientists involved (in particular the project scientist, Dr. R. Pfaff) to prepare several papers for publication in appropriate journals.

REFERENCES

Fejer, B.J., R.W. Reed, D.T. Farley, W.E. Swartz, and M.C. Kelley, Ion cyclotron waves as a possible source of resonant auroral radar echoes, J. Geophys. Res., 89(A1), 187-194, 1984.

Fejer, B.J., J. Providakes, D.T. Farley, and W.E. Swartz, Auroral E region plasma waves and elevated electron temperatures, J. Geophys. Res., 91(A12), 13583-13592, 1986.

Providakes, J., D.T. Farley, B.G. Fejer, J. Sahr, W.E. Swartz, I. Haggstrom, A. Hedberg, and J.A. Nordling, Observations of auroral E-region plasma waves and electron heating with EISCAT and a VHF radar interferometer, J. Atmos. and Terr. Phys., 50(4/5), 339-356, 1988.

Sahr, J., D.T. Farley, W.E. Swartz, Removal of aliasing in pulse-to-pulse doppler radar measurements, Radio Sci., accepted for publication, 1989.

TABLE 1

ape03.spc.cat   Sun Feb 4 23:49:15 1990

1

rec	year	dayn	time	1pp	del	tau	averages
0	1989	62	1816:02	2600	300	240	8
1	1989	62	1816:06	2600	300	240	8
2	1989	62	1816:09	2600	300	240	7
3	1989	62	1816:27	2300	300	240	8
4	1989	62	1816:31	2300	300	240	8
5	1989	62	1816:35	2300	300	240	8
6	1989	62	1816:39	2300	300	240	8
7	1989	62	1816:43	2300	300	240	8
8	1989	62	1816:46	2300	300	240	8
9	1989	62	1816:50	2300	300	240	8
10	1989	62	1816:54	2300	300	240	8
11	1989	62	1816:58	2300	300	240	8
12	1989	62	1817:01	2300	300	240	8
13	1989	62	1817:05	2300	300	240	8
14	1989	62	1817:09	2300	300	240	8
15	1989	62	1817:12	2300	300	240	8
16	1989	62	1817:16	2300	300	240	8
17	1989	62	1817:20	2300	300	240	8
18	1989	62	1817:24	2300	300	240	8
19	1989	62	1817:27	2300	300	240	1
rec	year	dayn	time	1pp	del	tau	averages
20	1989	62	1817:27	2300	300	240	8
21	1989	62	1817:31	2300	300	240	8
22	1989	62	1817:34	2300	300	240	8
23	1989	62	1817:38	2300	300	240	8
24	1989	62	1817:42	2300	300	240	8
25	1989	62	1817:46	2300	300	240	8
26	1989	62	1817:49	2300	300	240	8
27	1989	62	1817:53	2300	300	240	8
28	1989	62	1817:57	2300	300	240	8
29	1989	62	1818:01	2300	300	240	8
30	1989	62	1818:04	2300	300	240	8
31	1989	62	1818:08	2300	300	240	8
32	1989	62	1818:12	2300	300	240	8
33	1989	62	1818:16	2300	300	240	8
34	1989	62	1818:19	2300	300	240	8
35	1989	62	1818:23	2300	300	240	8
36	1989	62	1818:26	2300	300	240	8
37	1989	62	1818:31	2300	300	240	8
38	1989	62	1818:34	2300	300	240	8
39	1989	62	1818:38	2300	300	240	8
rec	year	dayn	time	1pp	del	tau	averages
40	1989	62	1818:42	2300	300	240	8
41	1989	62	1818:45	2300	300	240	8
42	1989	62	1818:49	2300	300	240	8
43	1989	62	1818:53	2300	300	240	8
44	1989	62	1818:57	2300	300	240	8
45	1989	62	1819:00	2300	300	240	8
46	1989	62	1819:04	2300	300	240	8
47	1989	62	1819:08	2300	300	240	8
48	1989	62	1819:11	2300	300	240	8
49	1989	62	1819:15	2300	300	240	8
50	1989	62	1819:19	2300	300	240	8
51	1989	62	1819:22	2300	300	240	8
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54	1989	62	1819:30	2300	300	240	8
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56	1989	62	1819:47	6000	3200	240	7
57	1989	62	1820:02	2400	300	240	1
58	1989	62	1820:11	2000	285	0	8
59	1989	62	1820:15	2000	285	0	8
rec	year	dayn	time	1pp	del	tau	averages
60	1989	62	1820:18	2000	285	0	8
61	1989	62	1820:22	2000	285	0	8
62	1989	62	1820:25	2000	285	0	8
63	1989	62	1820:29	2000	285	0	8
64	1989	62	1820:32	2000	285	0	8
65	1989	62	1820:36	2000	285	0	8
66	1989	62	1820:39	2000	285	0	8
67	1989	62	1820:43	2000	285	0	8
68	1989	62	1820:46	2000	300	240	8
69	1989	62	1820:50	2000	300	240	4
70	1989	62	1820:53	5000	300	240	4
71	1989	62	1820:55	5000	1985	240	4
72	1989	62	1820:58	2000	285	0	8
73	1989	62	1821:02	2000	285	0	8
74	1989	62	1821:05	2000	285	0	4
75	1989	62	1821:09	2000	285	0	8
76	1989	62	1821:12	2000	285	0	8
77	1989	62	1821:16	2000	285	0	8
78	1989	62	1821:20	2000	285	0	8
79	1989	62	1821:23	2000	285	0	8
rec	year	dayn	time	1pp	del	tau	averages
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81	1989	62	1821:30	2000	285	0	8
82	1989	62	1821:34	2000	300	240	8
83	1989	62	1821:38	2000	300	240	8
84	1989	62	1821:41	2000	300	240	4
85	1989	62	1821:43	5000	1985	240	4
86	1989	62	1821:45	2000	285	0	8
87	1989	62	1821:49	2000	285	0	8
88	1989	62	1821:53	2000	285	0	8
89	1989	62	1821:56	2000	285	0	8
90	1989	62	1822:00	2000	285	0	8
91	1989	62	1822:03	2000	285	0	8
92	1989	62	1822:07	2000	285	0	8
93	1989	62	1822:10	2000	285	0	8
94	1989	62	1822:14	2000	285	0	8
95	1989	62	1822:18	2000	285	0	8
96	1989	62	1822:21	2000	300	240	8
97	1989	62	1822:25	2000	300	240	8
98	1989	62	1822:28	2000	300	240	8
99	1989	62	1822:30	5000	1985	240	4
rec	year	dayn	time	1pp	del	tau	averages
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101	1989	62	1822:36	2000	285	0	8
102	1989	62	1822:40	2000	285	0	8
103	1989	62	1822:43	2000	285	0	8
104	1989	62	1822:47	2000	285	0	8
105	1989	62	1822:51	2000	285	0	8
106	1989	62	1822:54	2000	285	0	8
107	1989	62	1822:58	2000	285	0	8
108	1989	62	1823:01	2000	285	0	8
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111	1989	62	1823:12	2000	300	240	8
112	1989	62	1823:16	2000	300	240	4
113	1989	62	1823:17	5000	1985	240	4
114	1989	62	1823:20	2000	285	0	8
115	1989	62	1823:24	2000	285	0	3
116	1989	62	1823:42	2400	300	240	8
117	1989	62	1823:45	2400	300	240	8
118	1989	62	1823:49	2400	300	240	8
119	1989	62	1823:52	2400	300	240	8

ERRRIS 2 tape03

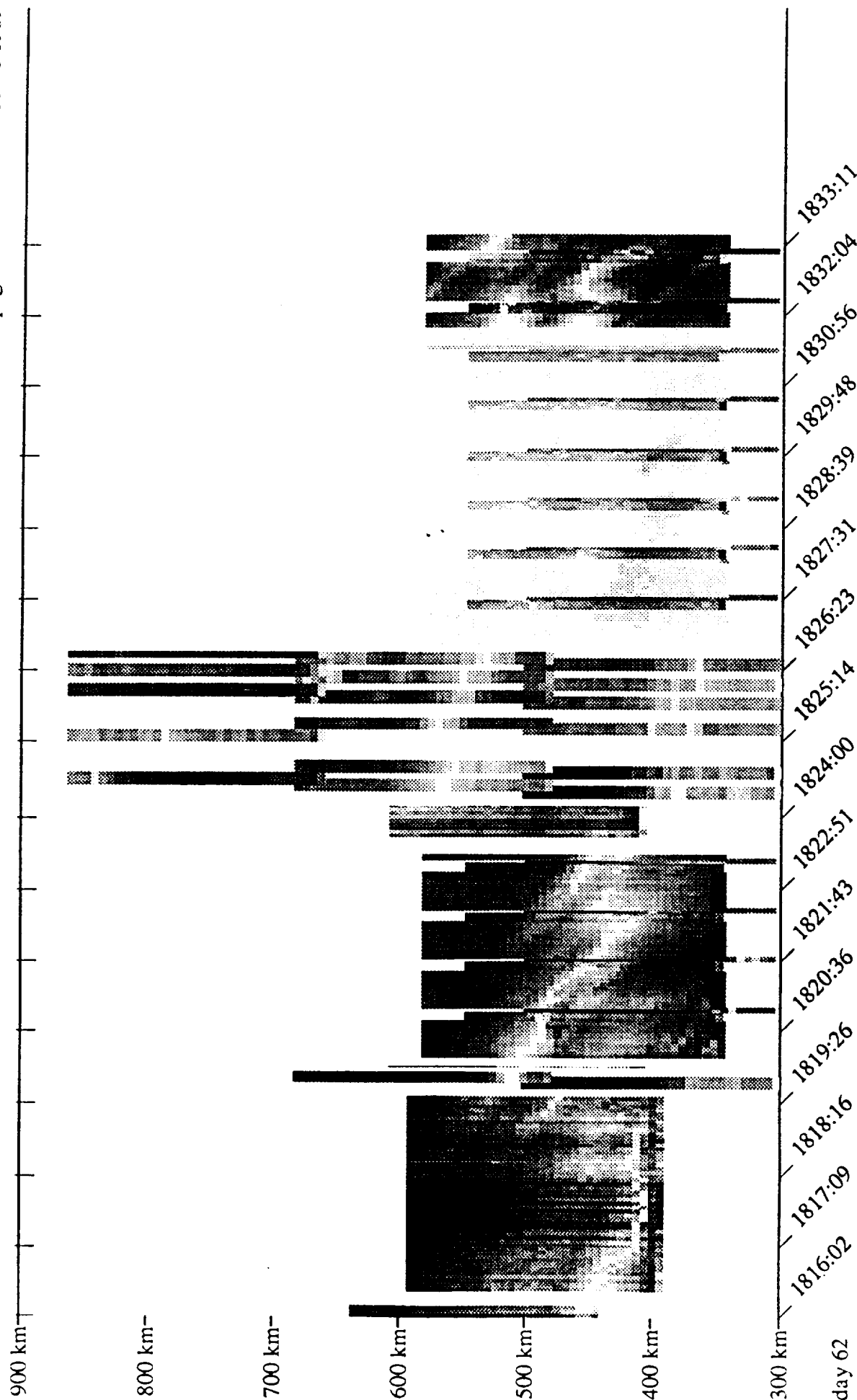page 1 starts: 3 Mar 18:16:02 1989; shows 20 minutes

page ends: 3 Mar 18:33:18 1989

Figure 1

ERRRIS 2 tape03

page 1 starts: 3 Mar 18:16:02 1989; shows 8 minutes

page ends: 3 Mar 18:23:52 1989)

600 km

550 km—

500 km—

450 km—

400 km

day 62

1816:02
1816:31
1816:58
1817:27
1817:57
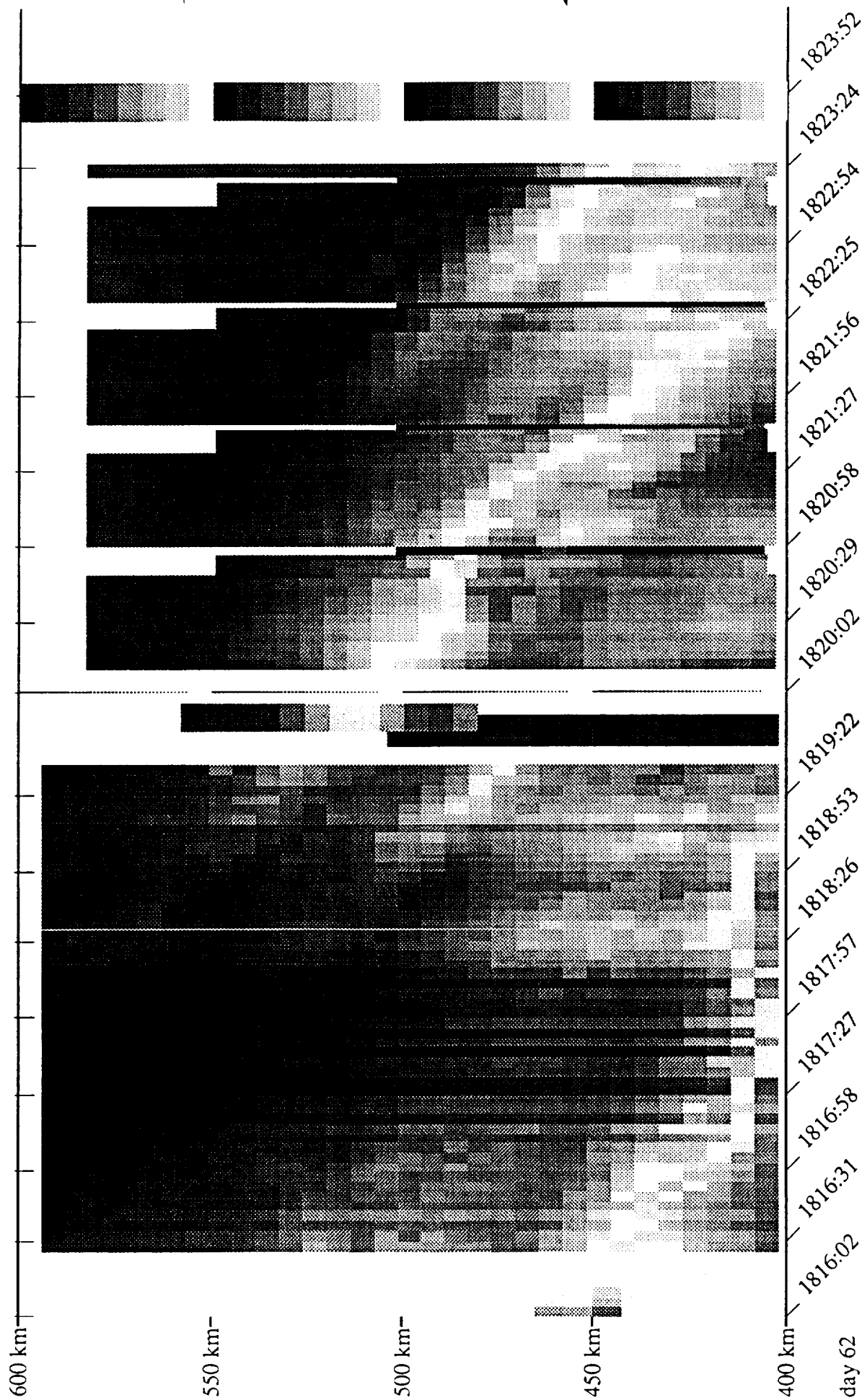1818:26
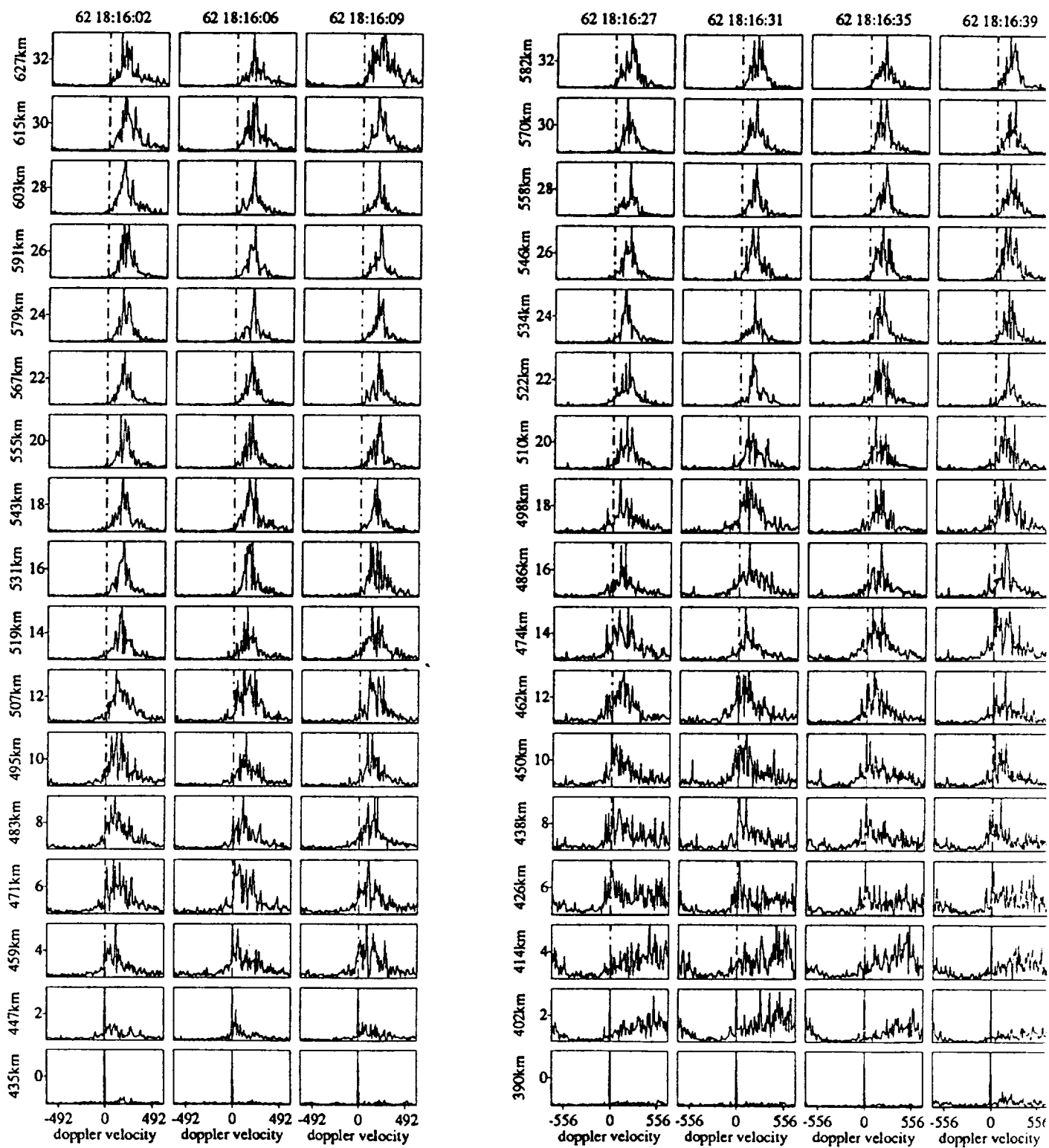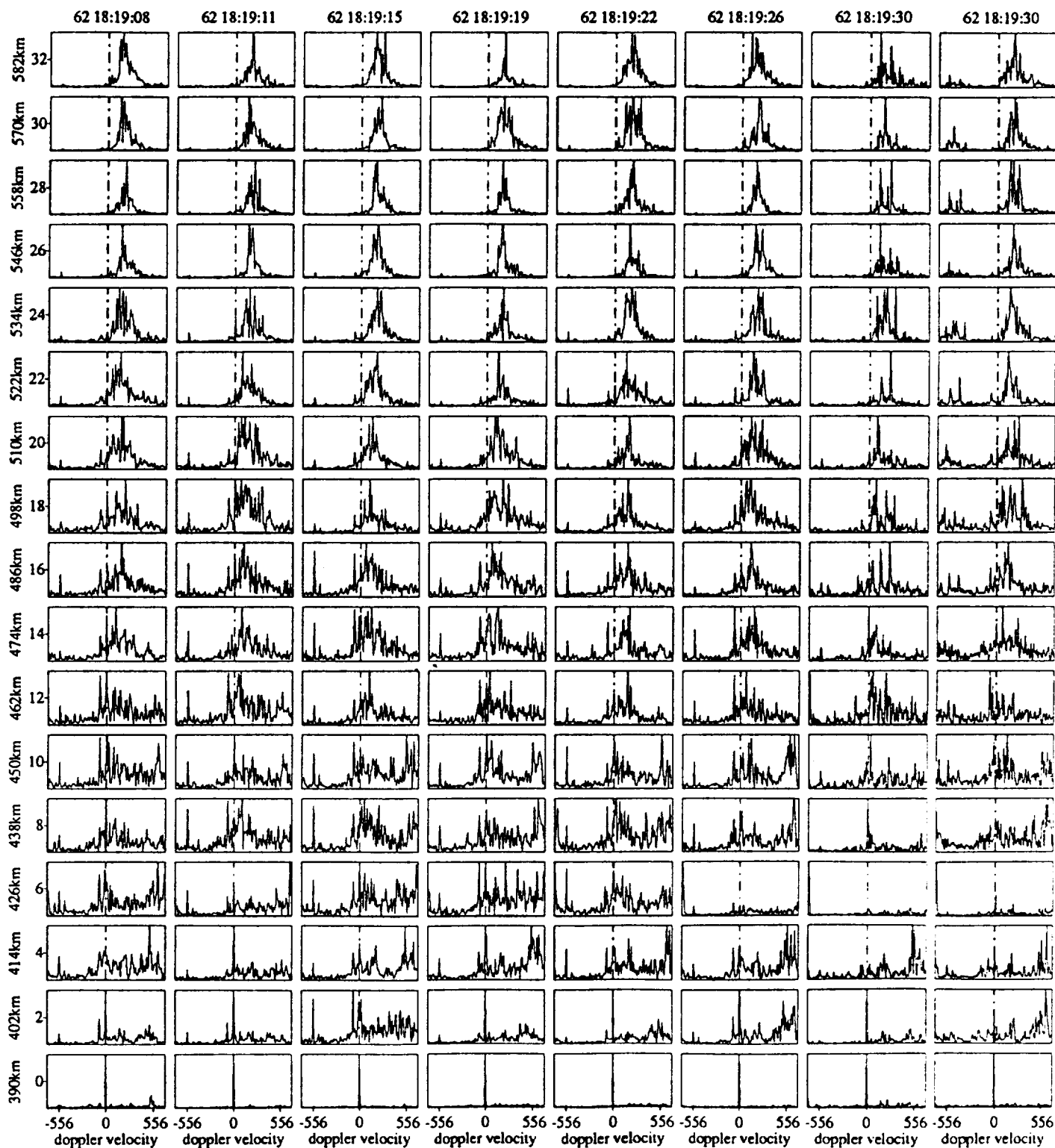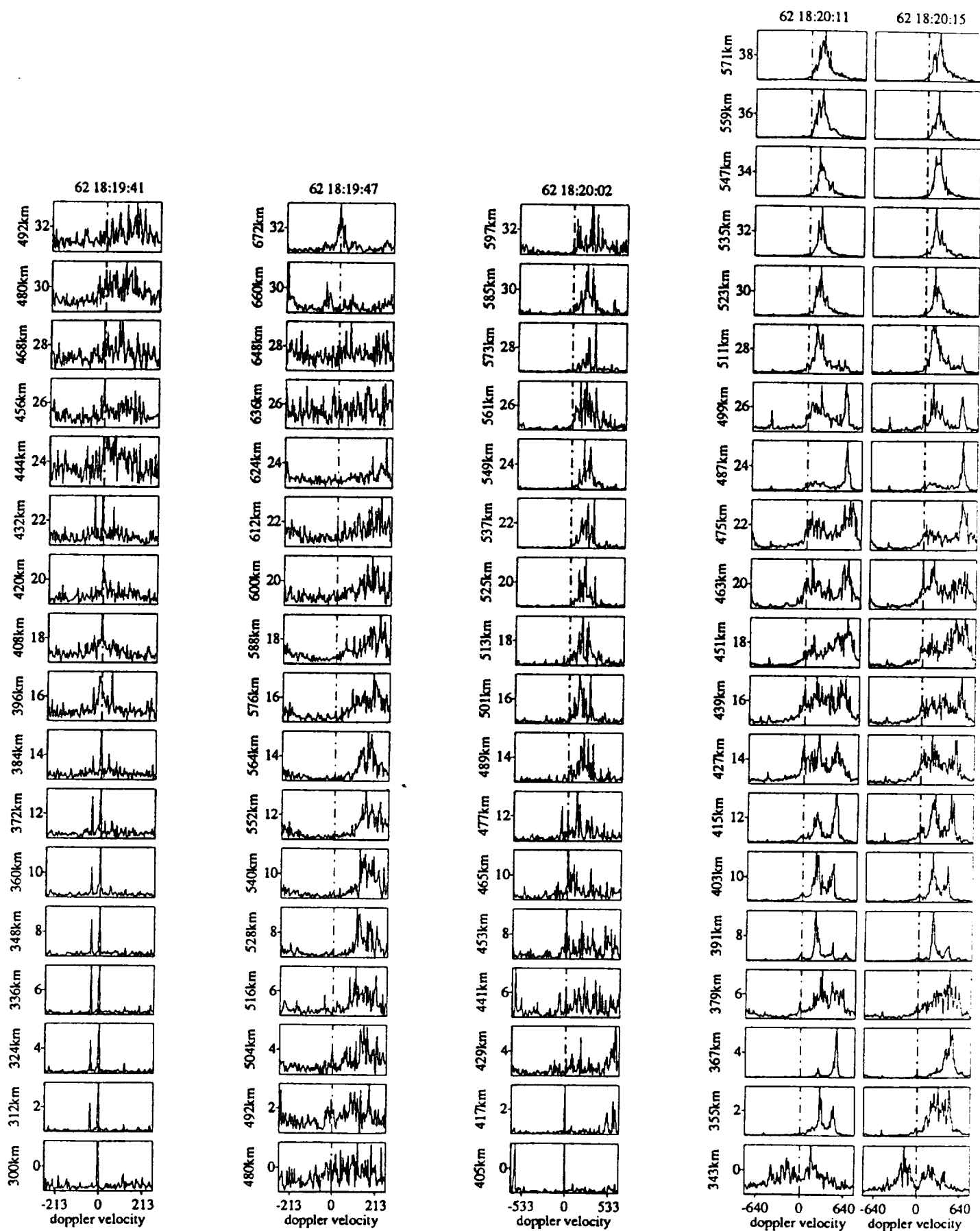1818:53
1819:22
1820:02
1820:29
1820:58
1821:27
1821:56
1822:25
1822:54
1823:24
1823:52

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

62 18:21:05 **62 18:21:09** **62 18:21:12** **62 18:21:16** **62 18:21:20** **62 18:21:23** **62 18:21:27** **62 18:21:30**
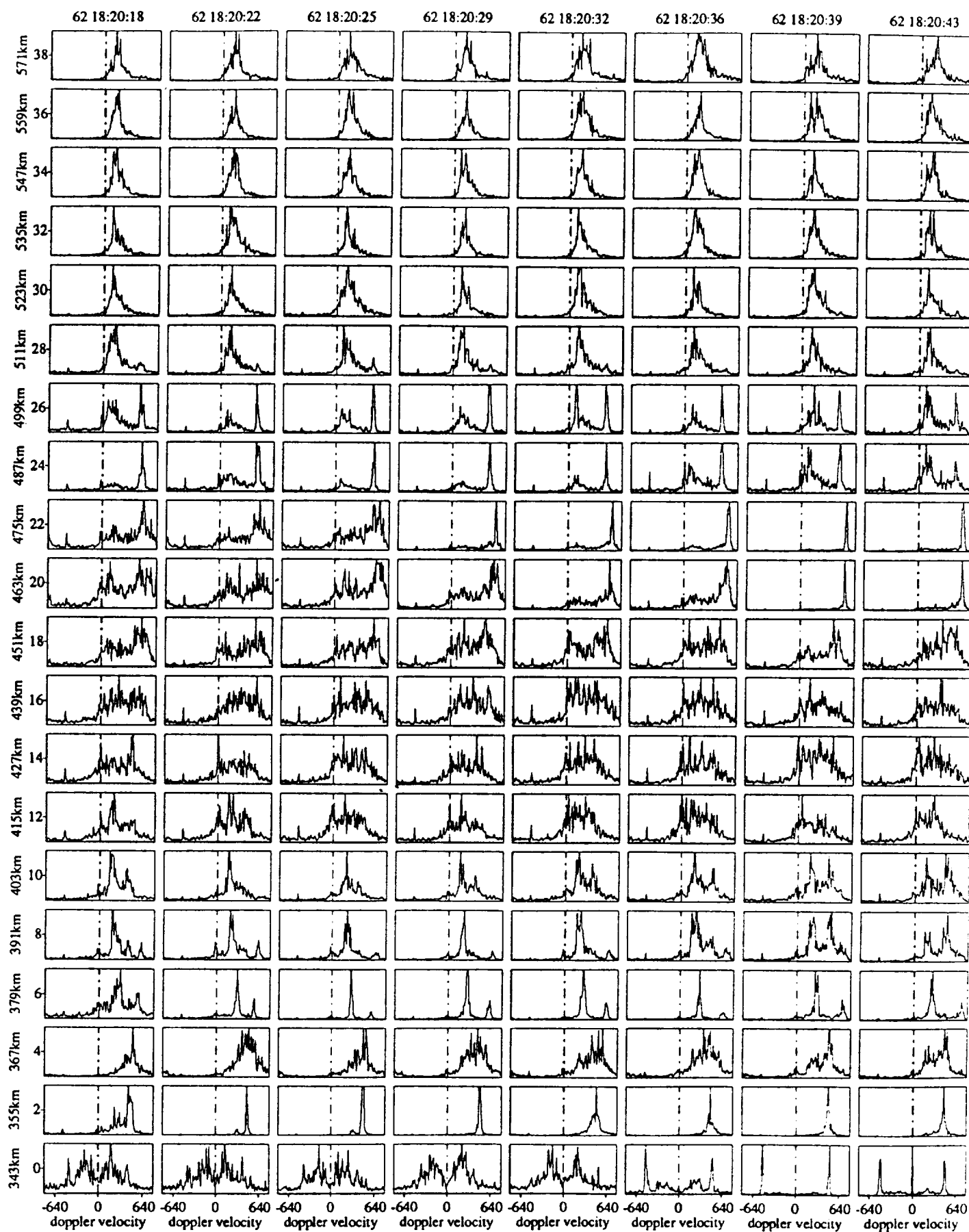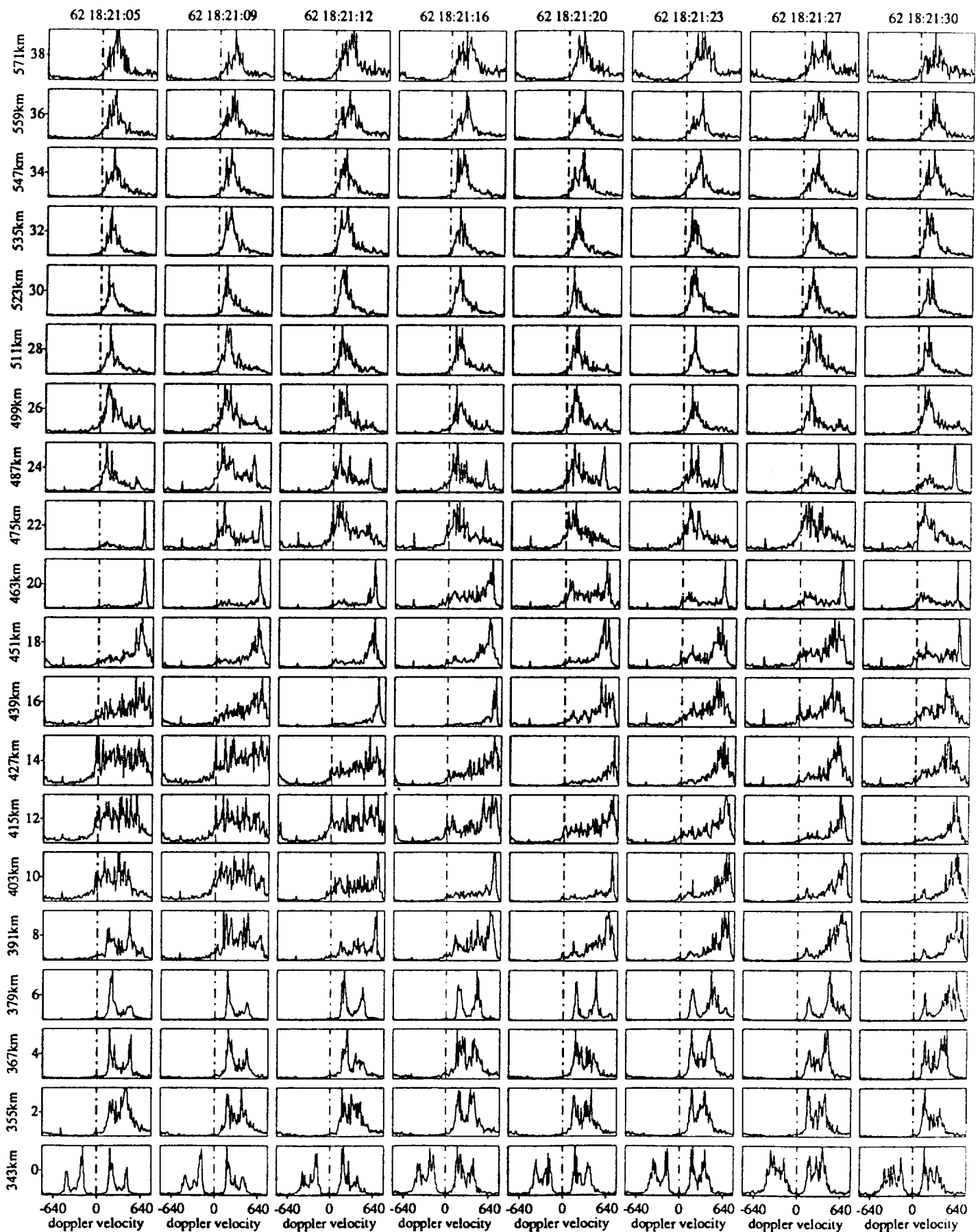
Figure 7

Figure 8

Figure 9

TABLE 2

2nd Rocket

Rocket
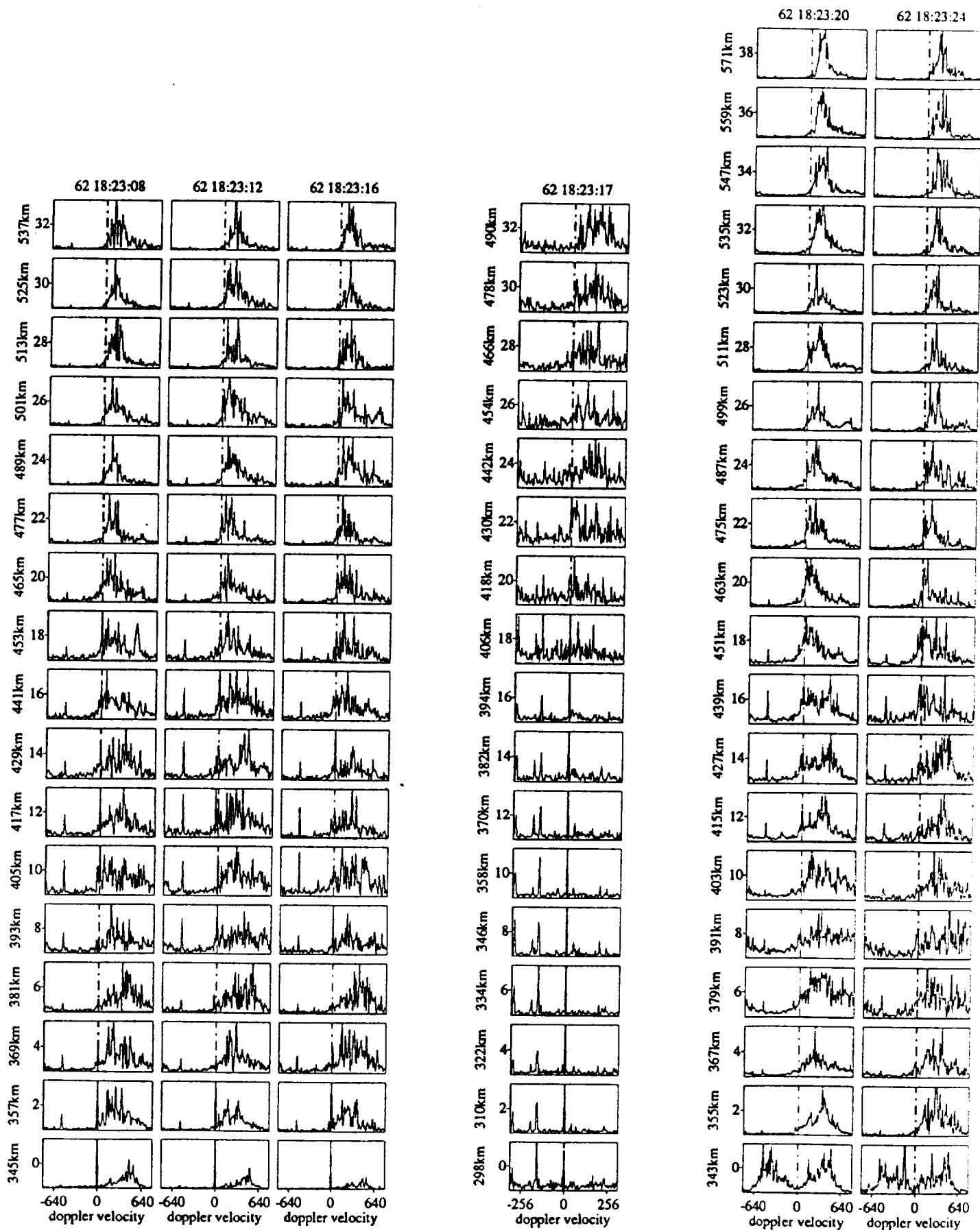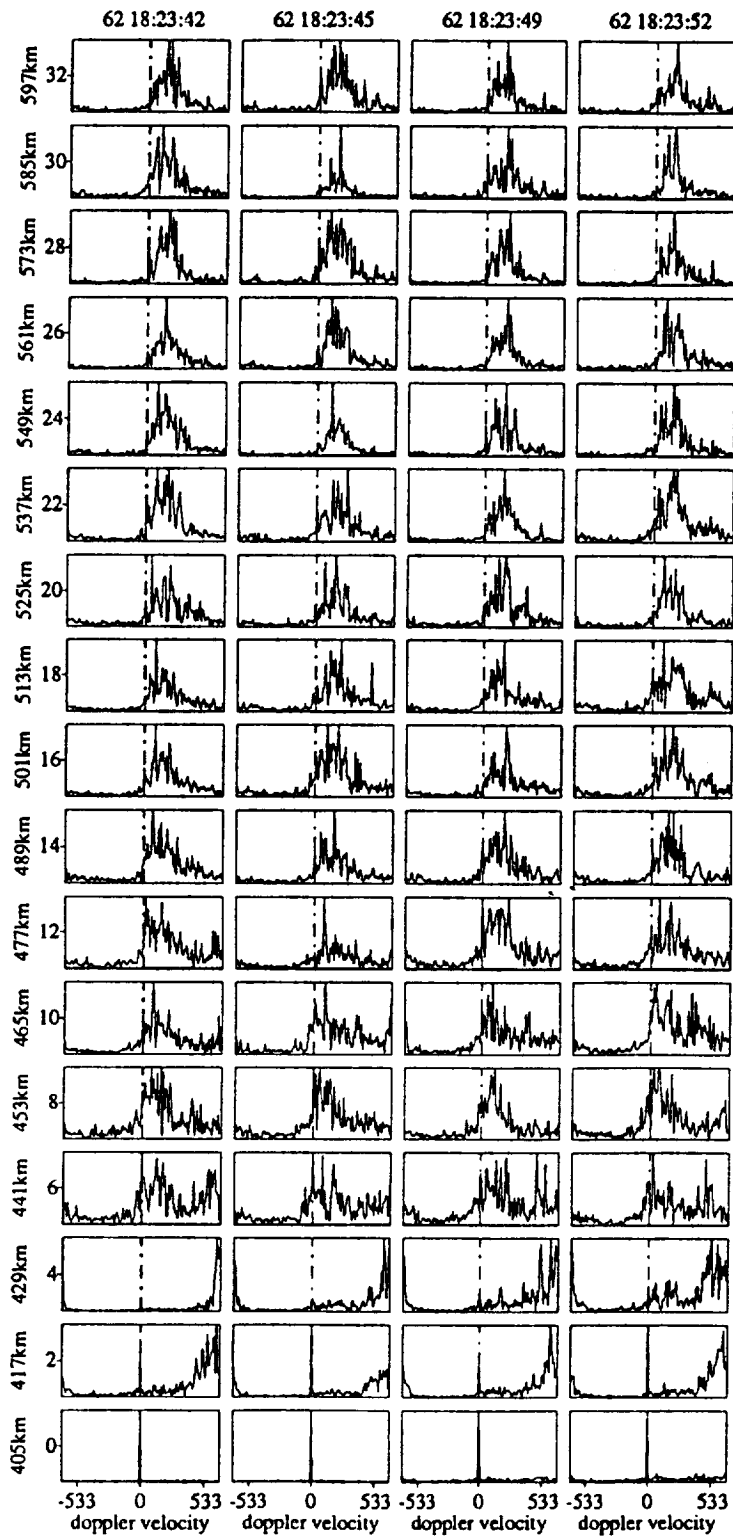
ape04.spc.cat   Sun Feb 4 22:09:35 1990   1

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3	1989	63	100:36	2000	285	0	8
4	1989	63	100:39	2000	285	0	8
5	1989	63	100:43	2000	285	0	8
6	1989	63	100:46	2000	285	0	8
7	1989	63	100:50	2000	285	0	8
8	1989	63	100:54	2000	285	0	8
9	1989	63	100:58	2000	285	0	8
10	1989	63	101:02	2000	300	240	8
11	1989	63	101:06	2000	300	240	8
12	1989	63	101:09	2000	300	240	4
13	1989	63	101:11	5000	1985	240	4
14	1989	63	101:14	2000	285	0	8
15	1989	63	101:18	2000	285	0	8
16	1989	63	101:21	2000	285	0	8
17	1989	63	101:25	2000	285	0	8
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25	1989	63	102:34	2000	285	0	8
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29	1989	63	102:50	2000	285	0	8
30	1989	63	102:53	2000	285	0	8
31	1989	63	102:57	2000	285	0	8
32	1989	63	103:01	2000	285	0	8
33	1989	63	103:05	2000	285	0	8
34	1989	63	103:08	2000	300	240	8
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36	1989	63	103:15	2000	300	240	4
37	1989	63	103:17	5000	1985	240	8
38	1989	63	103:20	2000	285	0	8
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59	1989	63	104:32	2000	285	0	8
60	1989	63	104:35	2000	285	0	8
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62	1989	63	104:43	2000	285	0	8
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64	1989	63	104:51	2000	300	240	8
65	1989	63	104:54	2000	300	240	4
66	1989	63	104:56	5000	1985	240	4
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73	1989	63	105:28	5000	1985	240	8
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75	1989	63	105:38	5000	1985	240	8
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82	1989	63	106:09	5000	1985	240	8
83	1989	63	106:14	5000	1985	240	8
84	1989	63	106:20	5000	1985	240	8
85	1989	63	106:25	5000	1985	240	8
86	1989	63	106:30	5000	1985	240	8
87	1989	63	106:35	5000	1985	240	8
88	1989	63	106:40	5000	1985	240	8
89	1989	63	106:46	5000	1985	240	8
90	1989	63	106:51	5000	1985	240	8
91	1989	63	106:56	5000	1985	240	8
92	1989	63	107:01	5000	1985	240	8
93	1989	63	107:06	5000	1985	240	1
94	1989	63	107:09	5000	2285	240	8
95	1989	63	107:14	5000	2285	240	2
96	1989	63	107:17	5000	2285	240	2
97	1989	63	107:22	5000	2585	240	8
98	1989	63	107:27	5000	2585	240	8
99	1989	63	107:32	5000	2585	240	8

ERRRIS 2 tape04

page 1 starts: 4 Mar 1:00:24 1989; shows 30 minutes   page ends: 7 Jan 44:00:12 1989

900 km

800 km

700 km

600 km

500 km

400 km

300 km

day 63

0100:24   0102:31   0104:13   0105:54   0107:38   0109:21   0111:03   0112:46
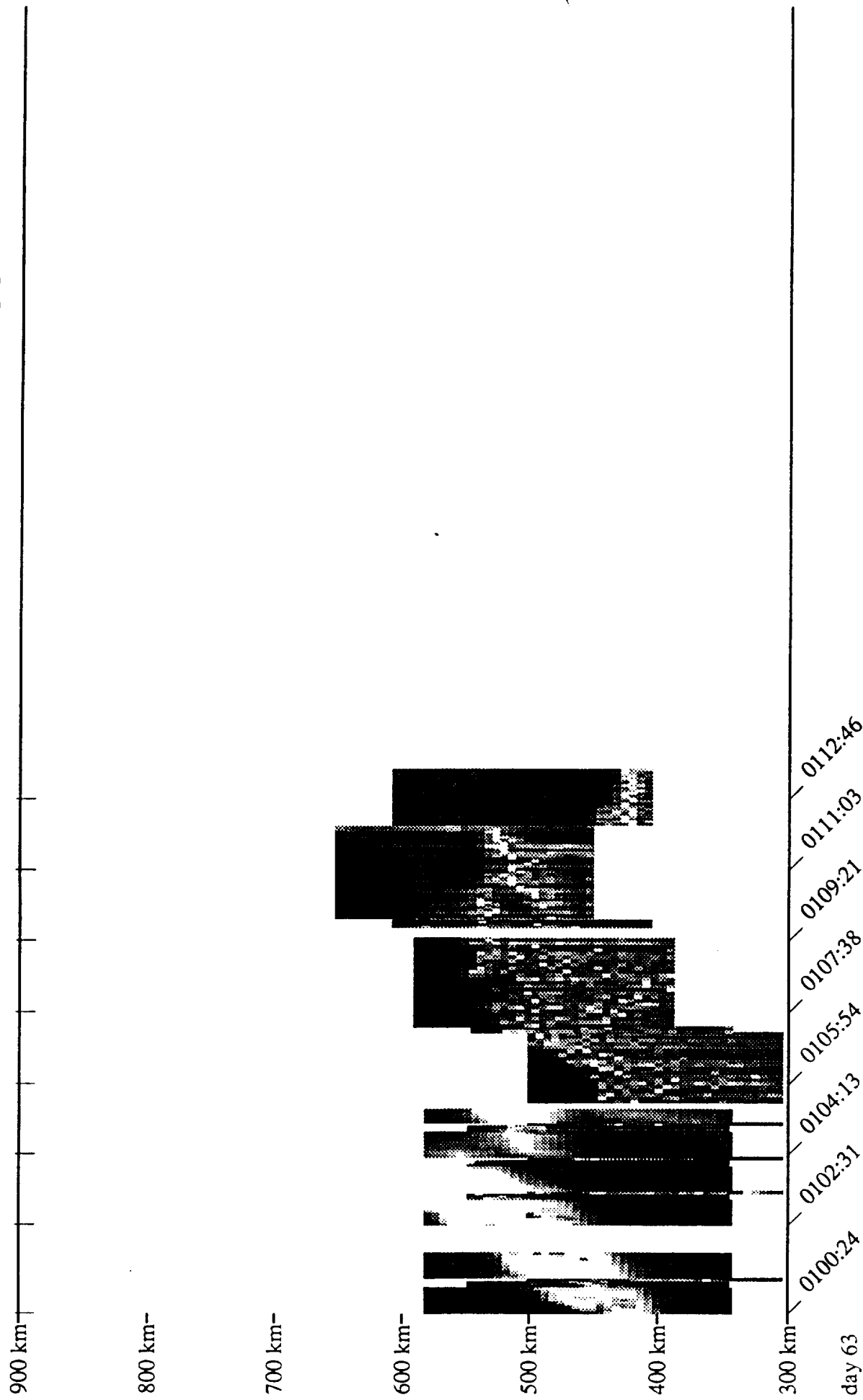
Figure 10

ERRRIS 2 tape04

page 1 starts: 4 Mar 1:00:24 1989; shows 9 minutes

page ends: 4 Mar 1:09:16 1989

600 km
550 km
500 km
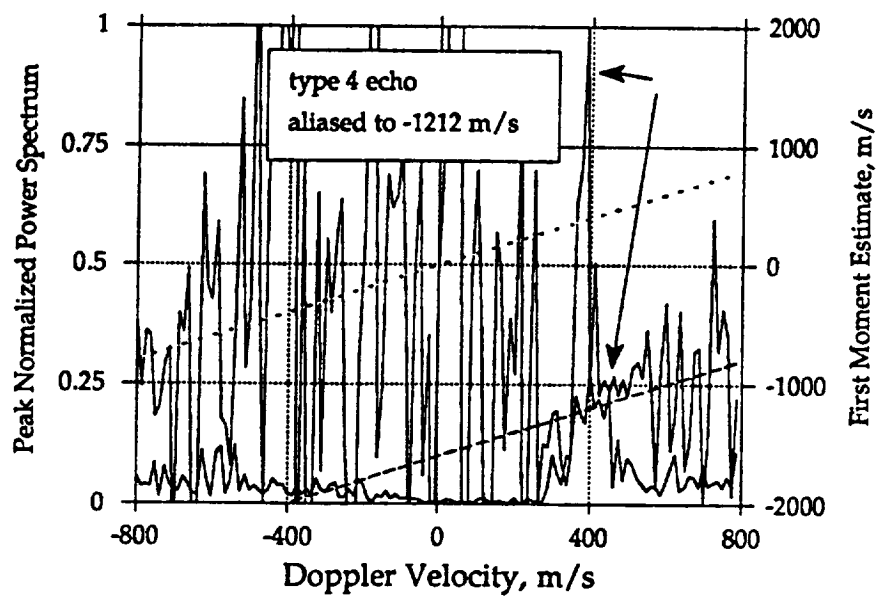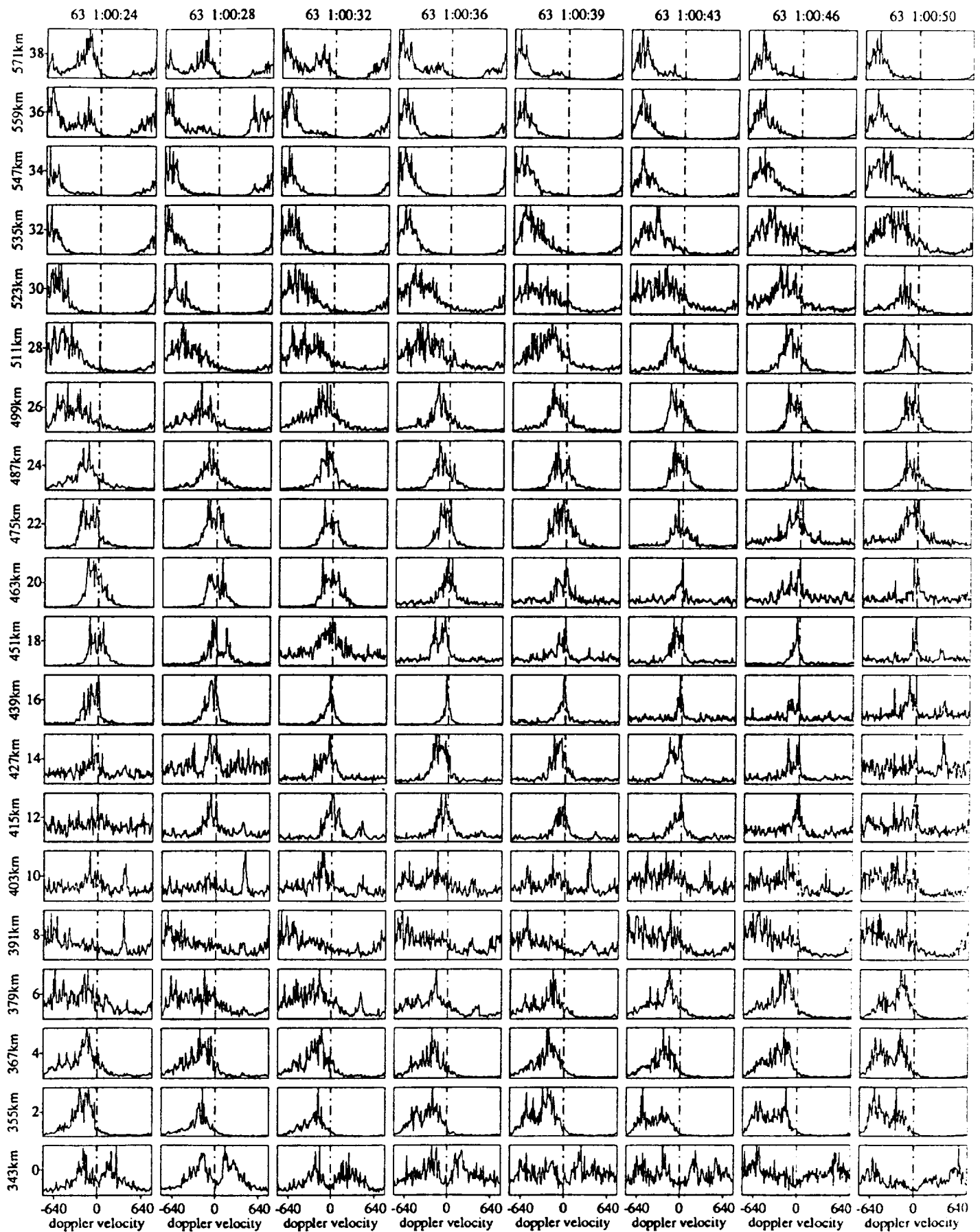450 km
400 km

0100:24
0100:58
0101:29
0102:31
0103:05
0103:39
0104:13
0104:46
0105:17
0105:49
0106:20
0106:51
0107:22
0107:53
0108:24
0108:55

day 63
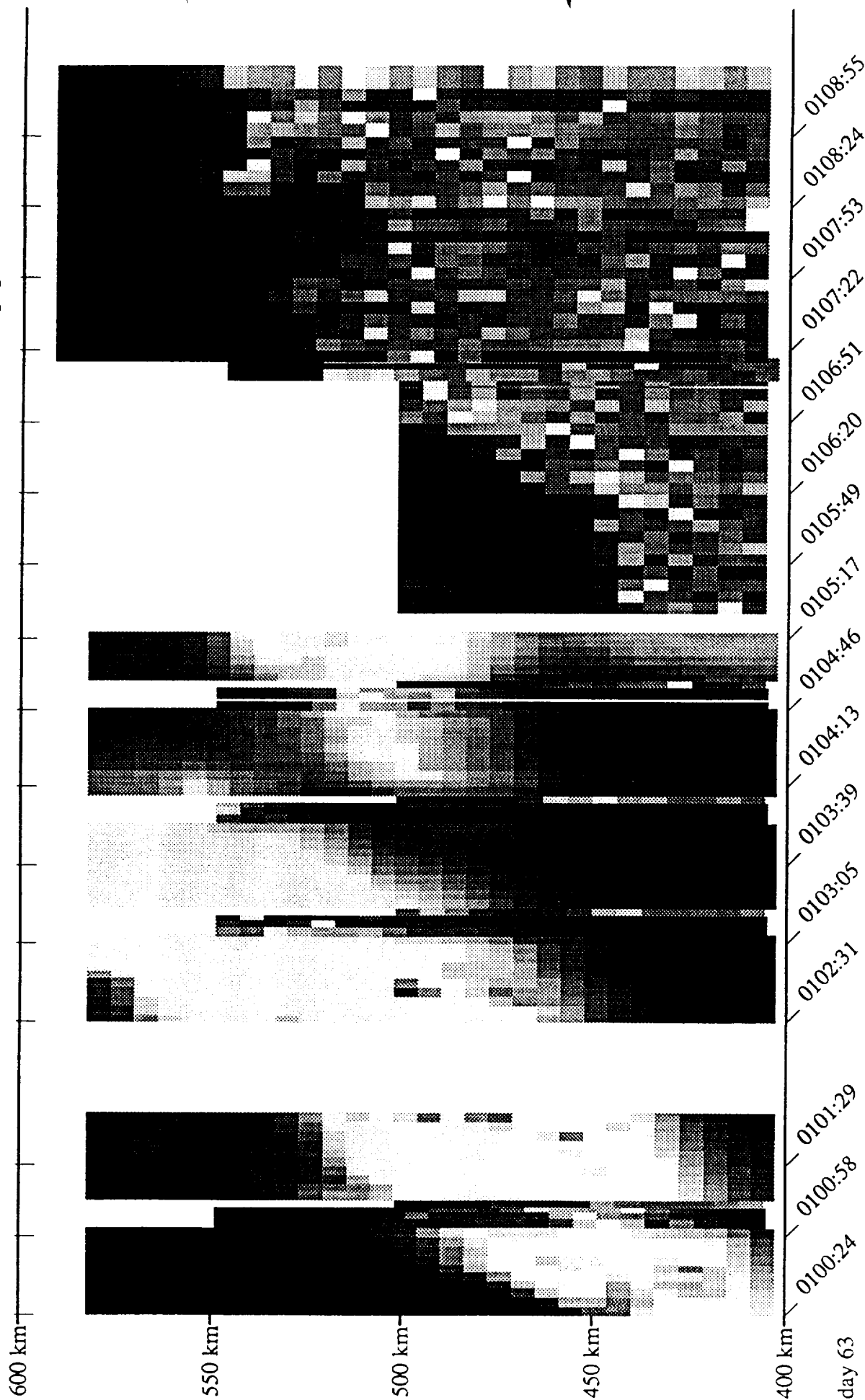
Figure 11

Power Spectrum and First Moment Estimate
CUPRI - ERRRIS 2 0103:57 d63 1989 (2 sec)

type 4 echo
aliased to -1212 m/s

Peak Normalized Power Spectrum
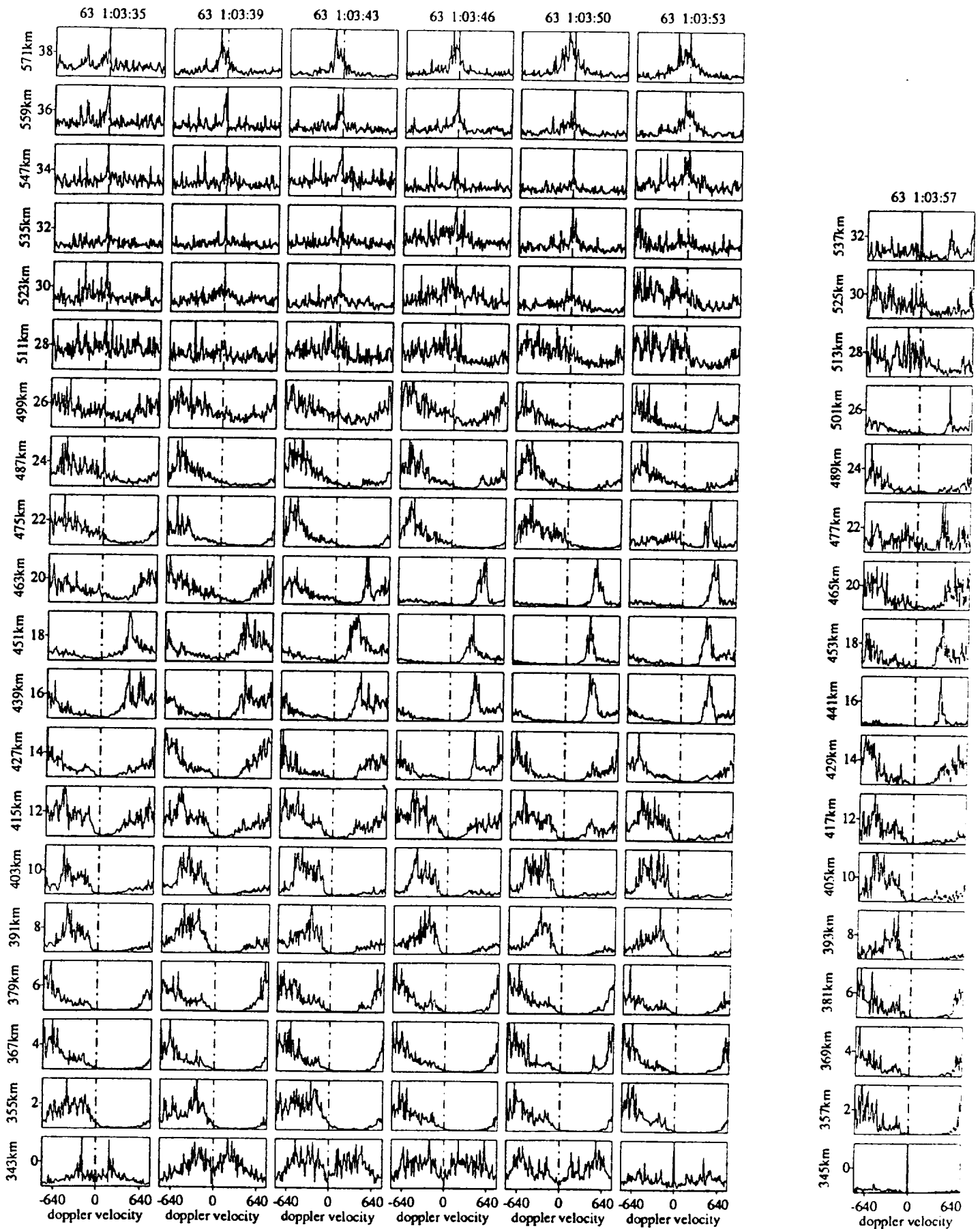
First Moment Estimate, m/s

Doppler Velocity, m/s
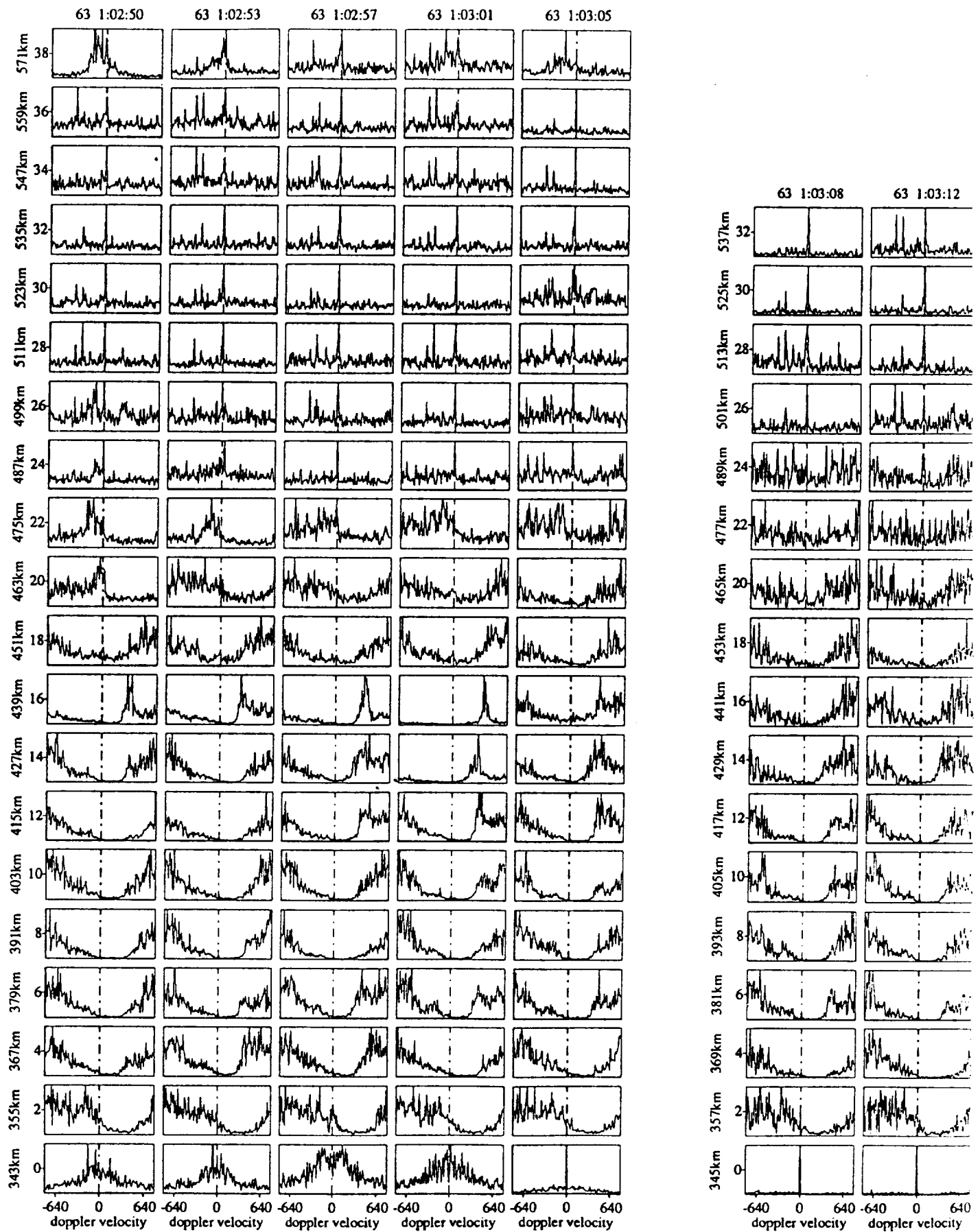
Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17